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CONCENTRATION STATISTICS BY WIND DIRECTION FOR 1976 ST. LOUIS SO_2 MEASUREMENTS AND MODEL ESTIMATES

by

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16. ABSTRACT

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Five statistics: 1) maximum, 2) second highest, 3) median, 4) mean, and 5) minimum related to concentration (both modeled and measured) were calculated for each direction for each of the 13 sites. Various displays of these statistics are used to explore the validity of the speculation regarding source types.

Procedures and displays developed can be used in data checking and quality control of emissions inventory data collection as well as in use of receptor models.

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In a previous evaluation of the urban air quality simulation model RAM using hourly SO_2 concentrations measured in 1976 at 13 sites duing the Regional Air Pollution Study conducted in St. Louis, Missouri, bias with stability was noted. A speculated cause of maxima from the model being calculated during stable conditions was that numerous small and medium point sources were included in the area source part of the emission inventory. Measured maxima occurred over a variety of conditions from unstable to stable.

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INTRODUCTION

Data collected during the Regional Air Pollution Study (RAPS) in St. Louis have been used in evaluation studies (Turner and Irwin, 1983a and 1983b) that compared RAM model estimates to measured SO_2 concentrations.

Turner and Irwin (1983b) indicated that significant bias existed in the model when both measurements and model results were examined according to stability. The model predicted highest concentrations under stable conditions, whereas measurements revealed the highest concentrations occurred over a variety of conditions ranging from moderately unstable to moderately stable. Although proof was unobtainable, a primary conjecture was that the inclusion of all point sources, with the exception of the largest 196, in the emission inventory as area sources contributed to the occurrence of the calculated maxima with stable conditions.

The investi tion reported here is to examine concentrations (both measured and modeled) by wind direction. It began as an attempt to see if patterns that could be related to point sources were revealed in the data analysis. This investigation continues use of the technique of partitioning data to better understand both how the model performs and how measured concentrations behave. It is certainly understood that any individual wind direction measurement may not necessarily represent the direction of flow of a pollutant from its source to a receptor and also that pollutant trajectories are seldom straight lines from source to receptor, but rather follow curved paths in response to temporally and spatially changing winds.

Data available for this study include hourly measured SO_2 concentrations for the year 1976 at each of 13 sampling sites. A map showing the locations of all sites is shown in Turner and Irwin (1983a). The number of hours of valid data ranged from 6088 hours at site 101, representing 69% of all possible hours, to 7571 hours at site 116 (86%). Hourly estimates of SO_2 from the model RAM were available for each hour. RAM uses a single wind direction for each hour's calculation, a mean wind direction which had been derived from the hourly measurements at 25 sites established for the RAPS study throughout St. Louis. Mean hourly wind directions were also measured at each sampling site. Measurements were made on 10-meter towers at sites 108, 114, 115, 116, and 121; and on 30-meter towers at sites 101, 103, 104, 105, 106, 113, 120, and 122. For the results reported here, modeled concentrations are examined only as they relate to the wind directions used as model input; measured concentrations are examined only as they relate to the wind directions measured at that site.

Wind direction frequencies were tabulated and plotted both for the model input values and for the measured directions at each of the 13 sites. These results were examined subjectively, particularly to determine if there appeared to be differences in the wind direction measured at 30 meters compared to the wind direction at 10 meters. There did appear to be a slight shift in the direction of the highest frequency. Three of the five 10-meter sites had highest wind frequency from the 160° to 170° sector. Five of the 30-m sites had highest frequencies between 185° and 200°. The maxima for the other three sites were between 160° and 180°. The shift in direction of these maxima frequencies is consistent with a clockwise rotation of winds with height that would be expected

due to surface effects. Figure 1 shows the direction frequencies for the model input (top), site 115 representative of 10-m tower sites, and site 101 representative of 30-m tower sites (bottom). The hash marks across the radial to the north of each site are at intervals of 20 hours.

DATA PREPARATION

Two files were the source of data for this investigation. One file, arranged with daily records, contained the modeled and estimated concentrations for all sites as well as the model input winds. The other file, with hourly records, contained the measured winds at all sites.

The first step in the data preparation was performed station by station. Using the modeled concentrations and model input winds as an example (this required only the one input file), an output data file was created with 360 records (one for each wind direction). Each record contained each concentration that occurred with wind from this direction and the sequential hour of the year when this occurred was paired with each concentration (in case subsequent analysis required linking meteorological conditions or time of day to each concentration). Similar files were created for each site and also for measured concentrations as a function of wind direction measured at the site (this required the second input file containing the measured winds). Since all data needed for file creation had to be read in and retained in core prior to writing the first record, efficiencies in core storage were made by breaking the wind direction into 5 sectors with the corresponding arrays able to hold different numbers of concentrations. For example, for directions 1

through 136 there were no more than 44 concentrations, but for directions 190-202 there were as many as 103. By using this sector approach, an array of size less than 20,000 was adequate to store the concentrations compared to 360 times 103 being more than 37,000. A similar sized array was used to store the hour designators corresponding to each concentration.

Each of 26 data files created as described above was then processed to create a second data file. Each record (each direction) was read and sorted with highest concentration first; the hour of the occurrence of this concentration was again linked to it. A new file was then created with 360 records of ordered concentrations. For the measured concentrations with measured winds a 361st record was added containing the ordered concentrations for cases with missing wind directions.

The two files for each site, one for modeled concentrations as a function of model input wind direction, the other for measured concentrations as a function of measured onsite wind directions, were then analyzed to create a file for each site to be used as input to a graphics program. In creating this file, five statistics were determined for each direction: 1) maximum, 2) second highest, 3) median, 4) mean, and 5) minimum. The statistics file (one for each site) was used with a graphics program to plot the results as a function of wind direction. Only the results for three statistics: second-high, median, and minimum, are presented. (This is why the notation 2 3 5 is shown at the lower right inside the circle for each concentration plot.) Site numbers are shown at the upper left. The plots of modeled concentrations as a function

of model input wind direction are designated by a 4 at the lower left; plots of measured concentrations as a function of onsite measured wind directions are designated by a 5. Because of the 10° resolution in the directions, the resulting diagrams can have significant changes from one direction to the next giving the appearance of sharp spikes. Hence, the diagrams may be referred to as "pollution zinnias", in contrast to "wind roses" or "pollution roses" that, due to 16 or 36 point resolution, have smoother "petals".

RESULTS

Figure 2 displays concentric plots of the second-high, median, and minimum for modeled concentrations for the five receptor sites in the south-central part of the sampling grid. The hash marks across the radial to the north of each site are at intervals of 200 micrograms per cubic meter. The spacing and position of the station circles is according to their location so that they are oriented correctly with respect to one another. There are numerous situations where 5 to 9 adjacent azimuths have second highest concentrations form a central spike with concentrations lower on each side. Also, there are a number of situations where the minimum for a direction is significantly higher than for nearby azimuths. In some cases, spikes due to a specific source can be seen at several receptors. Three sources with a combined average emission of more than 8600 grams per second are at azimuths of 262° from site 106, 264° from site 105, and 258° from site 103 at distances of 51, 56, and 60 km, respectively. These directions correspond with the spikes extending westward from these three sites in Figure 2. This is exactly what would be expected of a model having the characteristics of RAM, which assumes a steady wind flow between source and receptor.

The corresponding plot for measured concentrations at these five sites is shown in Figure 3. Striking, of course, are the high concentrations for site 104. These have been attributed (Ruff, 1981) to a nearby source that increased emissions markedly during November and December of 1976. From the plot, the source would be expected to be southwest of site 104. However, one is quick to note the significant number of excursions above 800 for second-highest concentration to the northwest through north of site 104. It is not possible to prove, but it can be speculated that some or all of these may be due to releases from the same plant southwest of site 104 that are carried northwest of the site and then caught in a shifting wind flow that comes from the northwest to the site.

It can be seen that measured spikes exist just south of west for sites 106 and 105 as noted for the modeled concentrations. However, no corresponding singular significant spike exists at site 103. Although, spread over greater azimuth ranges than those for the model, concentrations to the south-southwest of sites 106, 105, and 103 seem to have some correspondence to peaks in the modeled concentrations.

Figures 4 and 5 are for the modeled and measured concentrations respectively, for the remaining eight sites. The positions of these plots are correct relative to their actual location. The locations of the five sites depicted in Figures 2 and 3 are shown at the bottom of Figures 4 and 5. Perhaps even more noticable in these two figures are the spikes over rather limited azimuth bands for modeled concentrations contrasted to broader azimuth regions of somewhat less magnitude for the measured

concentrations. Large spikes exceeding 400 at site 121, 700 at site 114, and 1200 at site 115 greatly exceed the second-highest measured concentrations which approach 400 only at site 115.

Figures 6 through 10 allow more detailed comparison of modeled and measured concentrations on a site by site basis. In each case, the modeled concentrations are on the left (labelled with a 4) and the measured concentrations are on the right (labelled with a 5).

DISCUSSION AND CONCLUSIONS

Although the impetus for this analysis was to see if there was any evidence of measured concentrations resulting from point sources that were not in the inventory, the depictions appear to offer no concrete conclusions in this direction. Although the many spikes that appear in the measured concentration diagrams may result from many point sources, they may just as easily result from measured winds occurring near the general direction of the upwind source such that 10 to 15 spikes over a 20° to 25° azimuth range may result from the same source.

Obvious difficulties are that the most representative wind measurement at a monitoring site may still not represent the actual direction of transport of air arriving at that site, and that pollutant trajectories are seldom straight lines. In spite of these shortcomings, it would still appear that organization of data by observed wind direction, and the calculation and graphical display of particular statistics for each direction may be useful. A specific application might be when air quality data are being collected at the time of the conduct of an emissions inventory. An

examination of graphical output would indicate the significant sources, especially those near the monitoring site, and steps could be taken to insure their inclusion in the emission inventory.

Such analysis would also be useful when combined with receptor modeling. It is not necessary to collect data continuous in time but to have a wind direction measurement at the monitoring site associated with each air quality measurement. This necessitates air quality sampling over short time periods (generally not longer than an hour) for ease in relating a wind direction to the air quality measurement.

Statistics in somewhat different form, such as, frequency of concentration above a particular threshold when the wind is from this direction might be used instead of concentration statistics. Such statistics would not have to rely on accurate air quality measurements, but only on whether the pollutant level is high or low.

This study indicates that statistics in large quantity, such as 360 values per site, can be made more managable, if only in a subjective way, through the use of graphical presentations. Such presentations enable the viewer to assimilate the important and discard the unimportant readily as the graphs are examined. The variability or scatter, which so dominates model and measured concentrations, is also visually apparent.

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The author appreciates the use of the file of measured winds prepared by Dale Coventry, the use of the file of measured and modeled concentrations prepared by John Irwin, and the secretarial assistance of Sylvia Alston.

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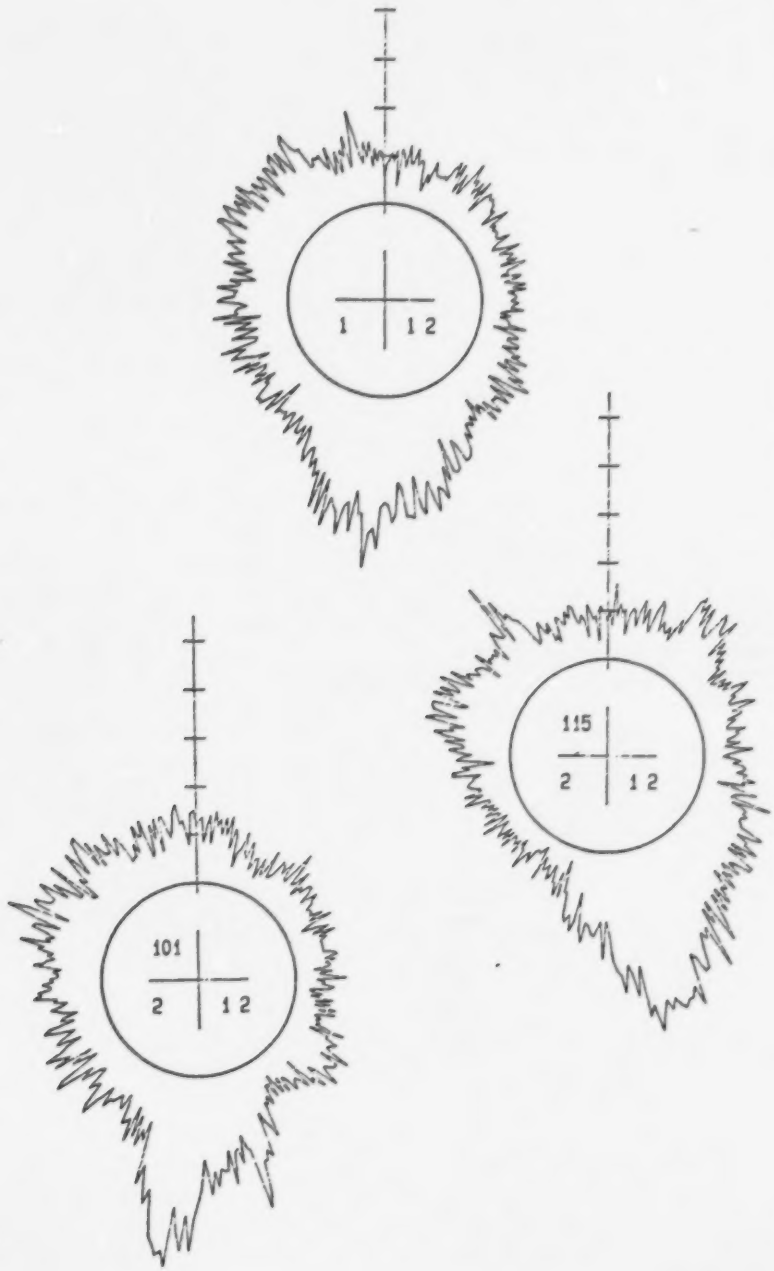

Figure 1. Direction frequencies for model input winds (top) and for measured winds at site 115 (10 m) and site 101 (30 m).

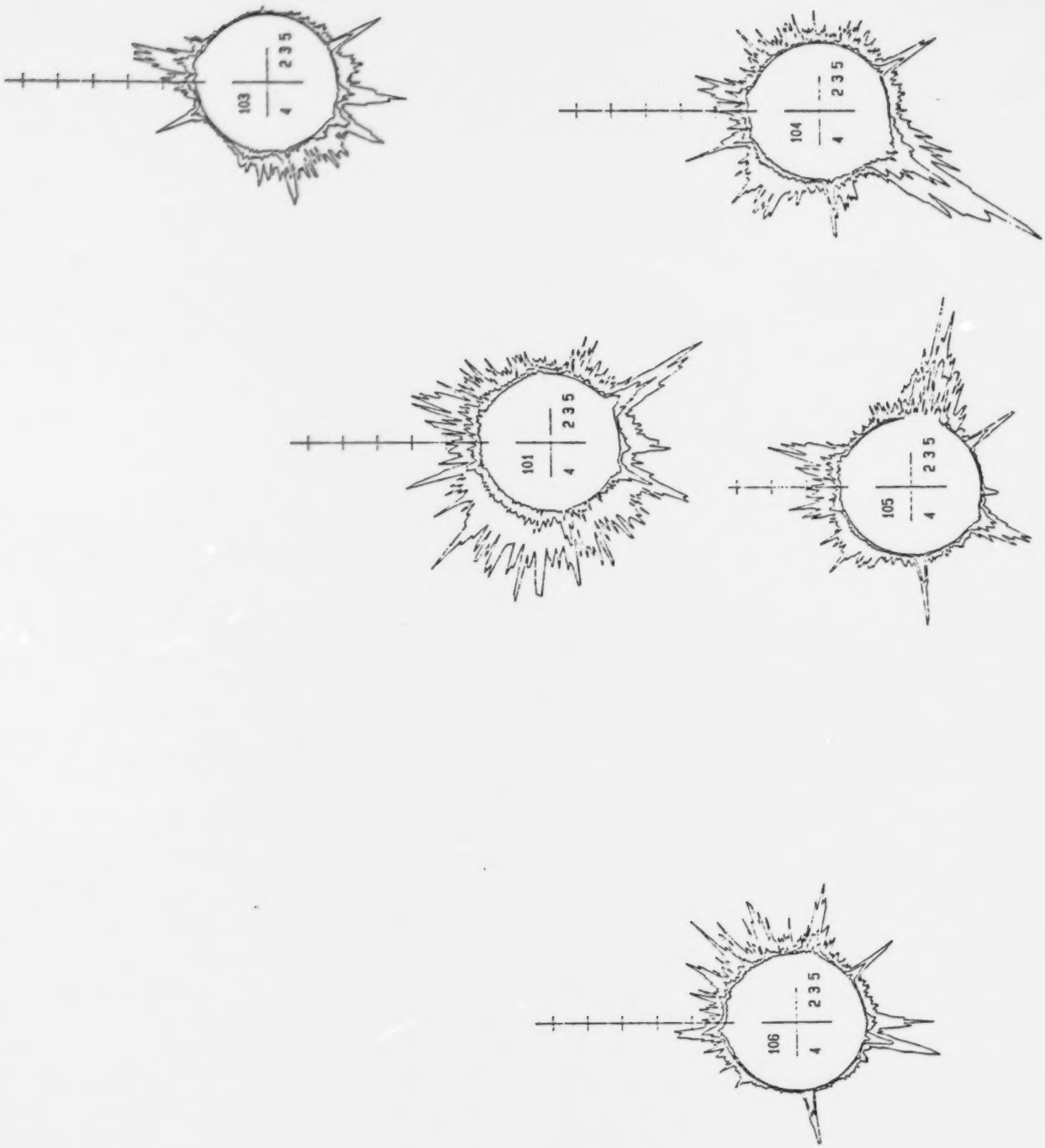

Figure 2. Modeled "pollution zinnias" for the five sites in the south-central part of the grid.

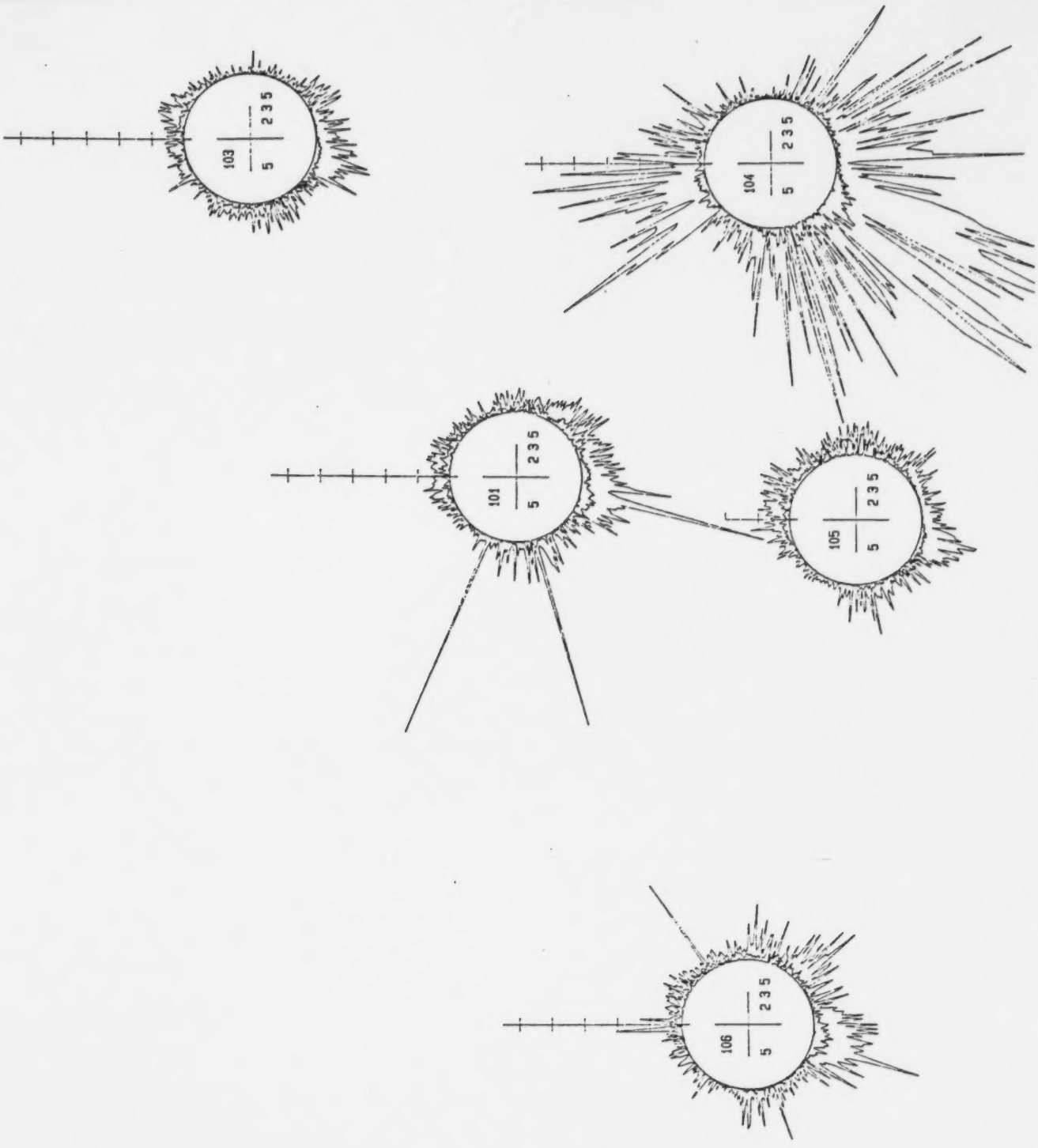

Figure 3. Measured "pollution zinnias" for the five sites in the south-central part of the grid.

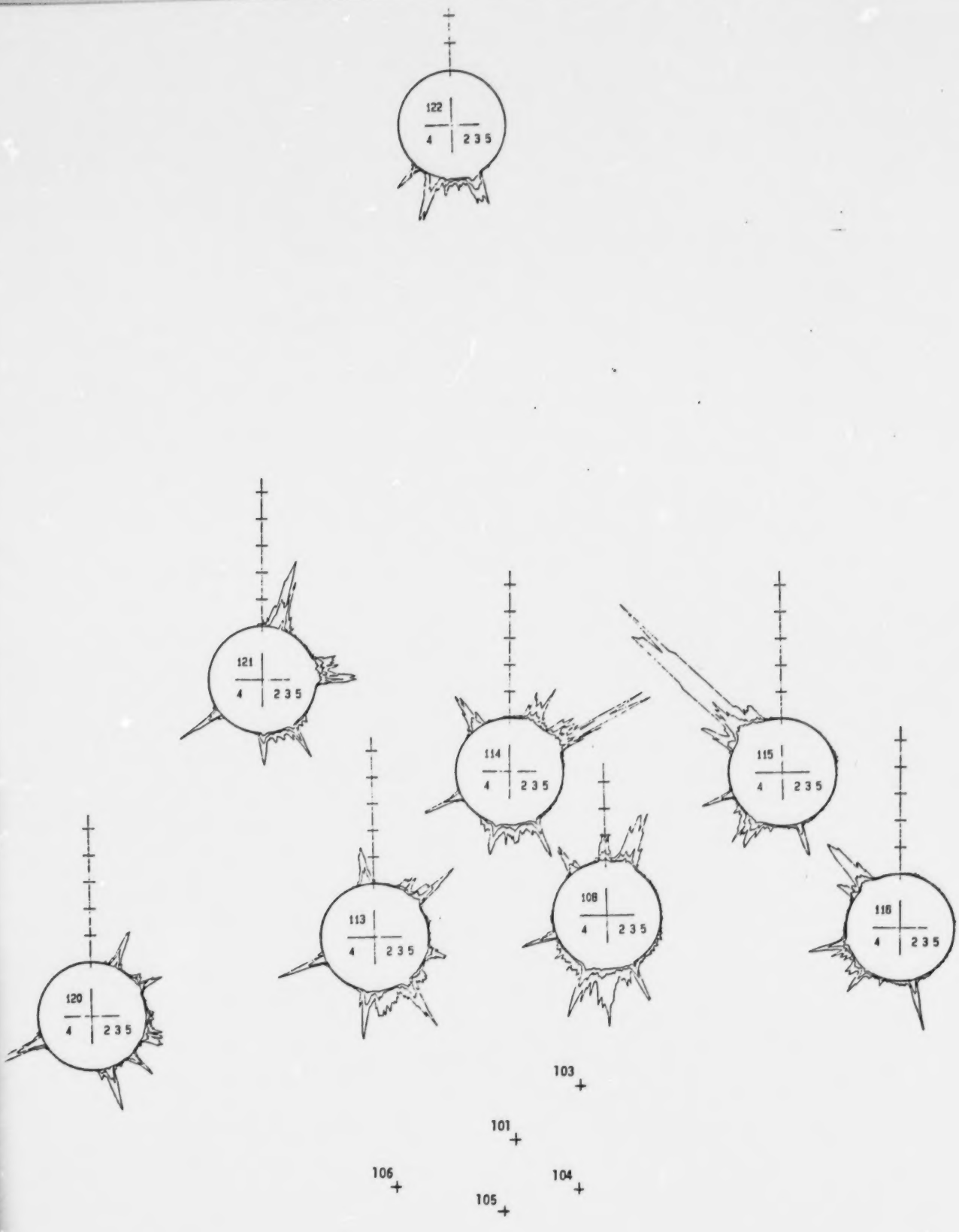

Figure 4. Modeled "pollution zinnias" for the eight northern sites.

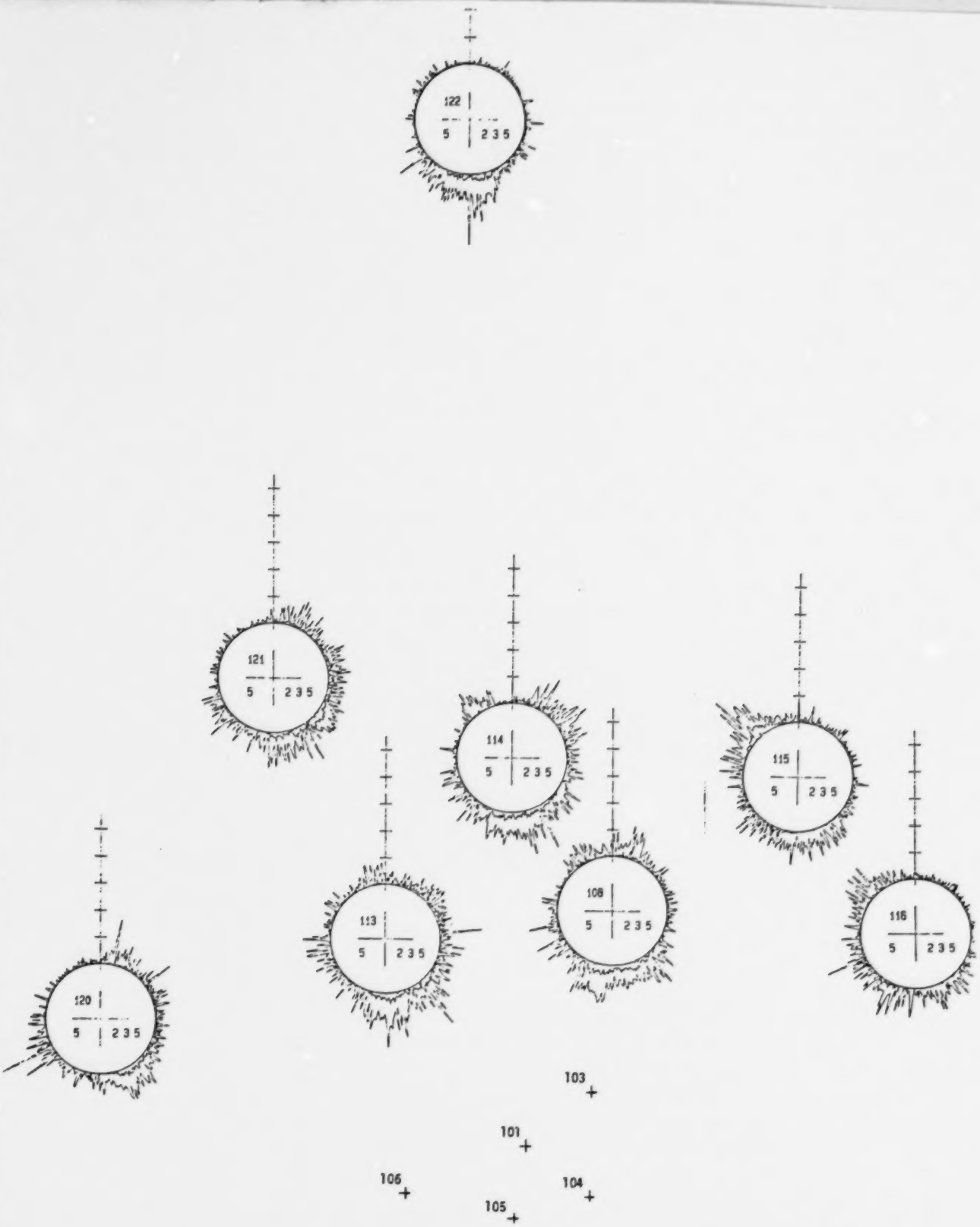

Figure 5. Measured "pollution zinnias" for the eight northern sites.

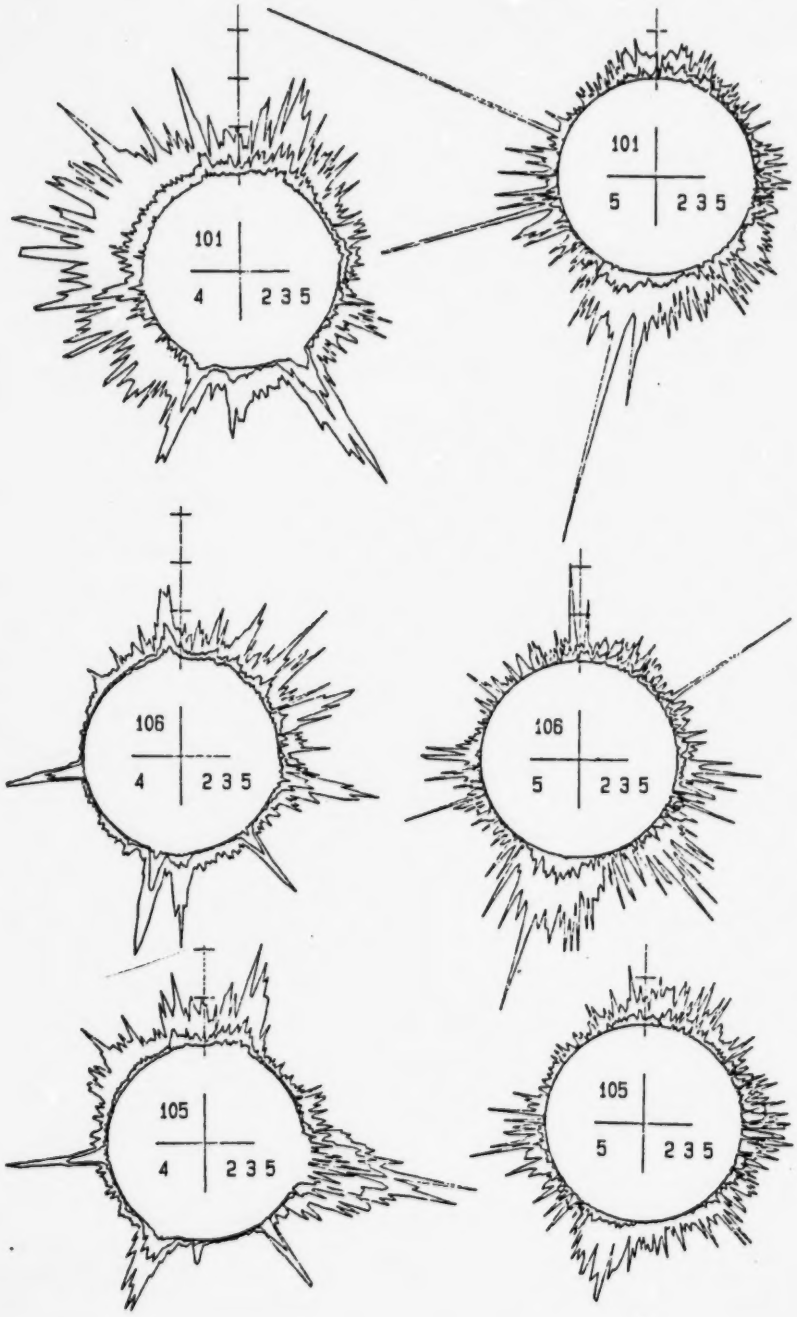

Figure 6. Modeled (left) and measured (right) "pollution zinnias" for sites 101, 106, and 105 (the southwest part of the grid).

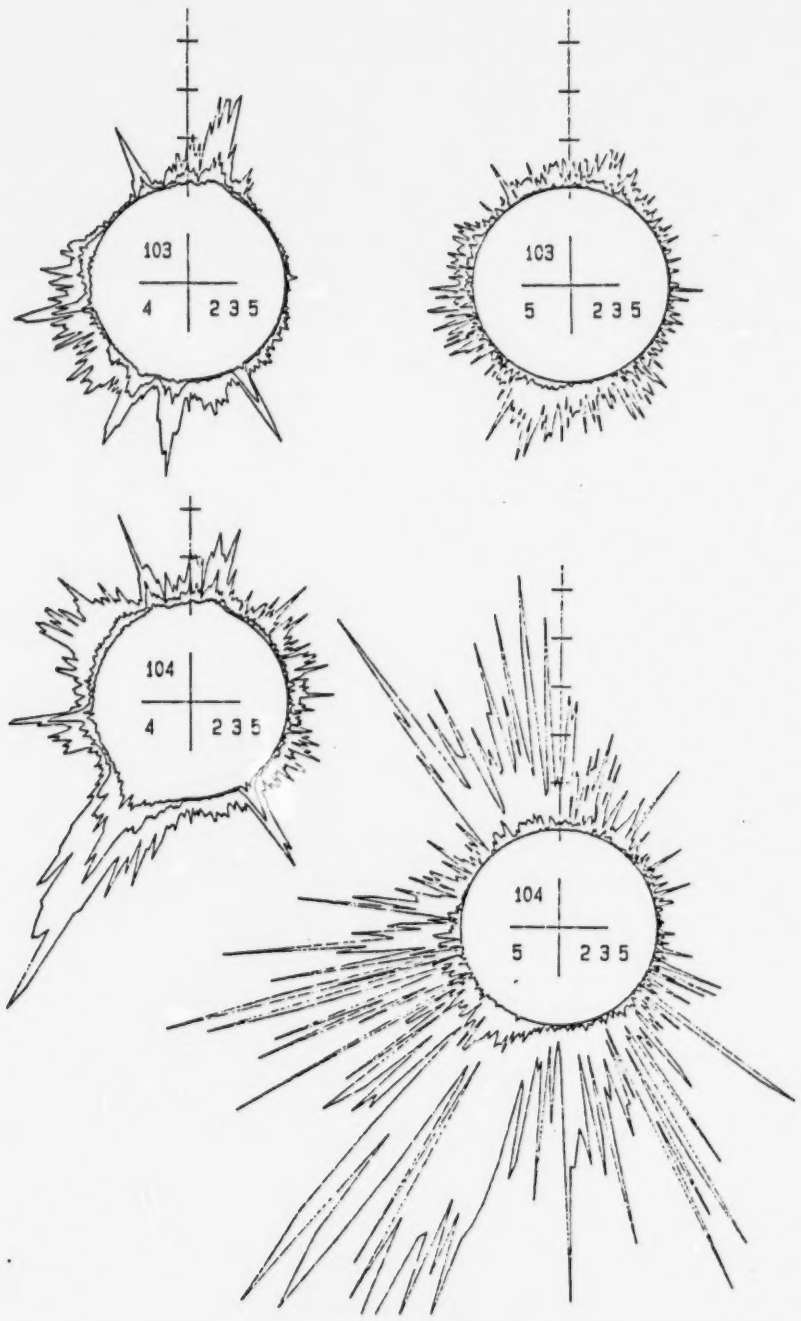

Figure 7. Modeled (left) and measured (right) "pollution zinnias" for sites 103 and 104 (the southeast part of the grid).

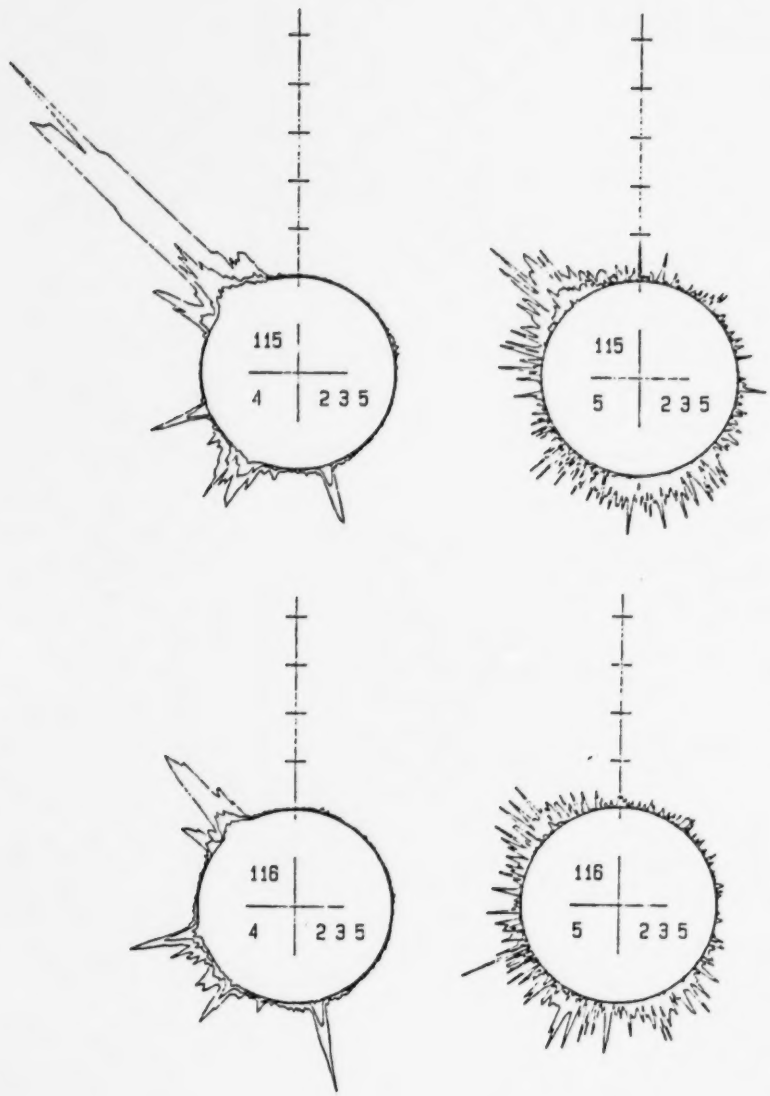

Figure 8. Modeled (left) and measured (right) "pollution zinnias" for sites 115 and 116 (the northeast part of the grid).

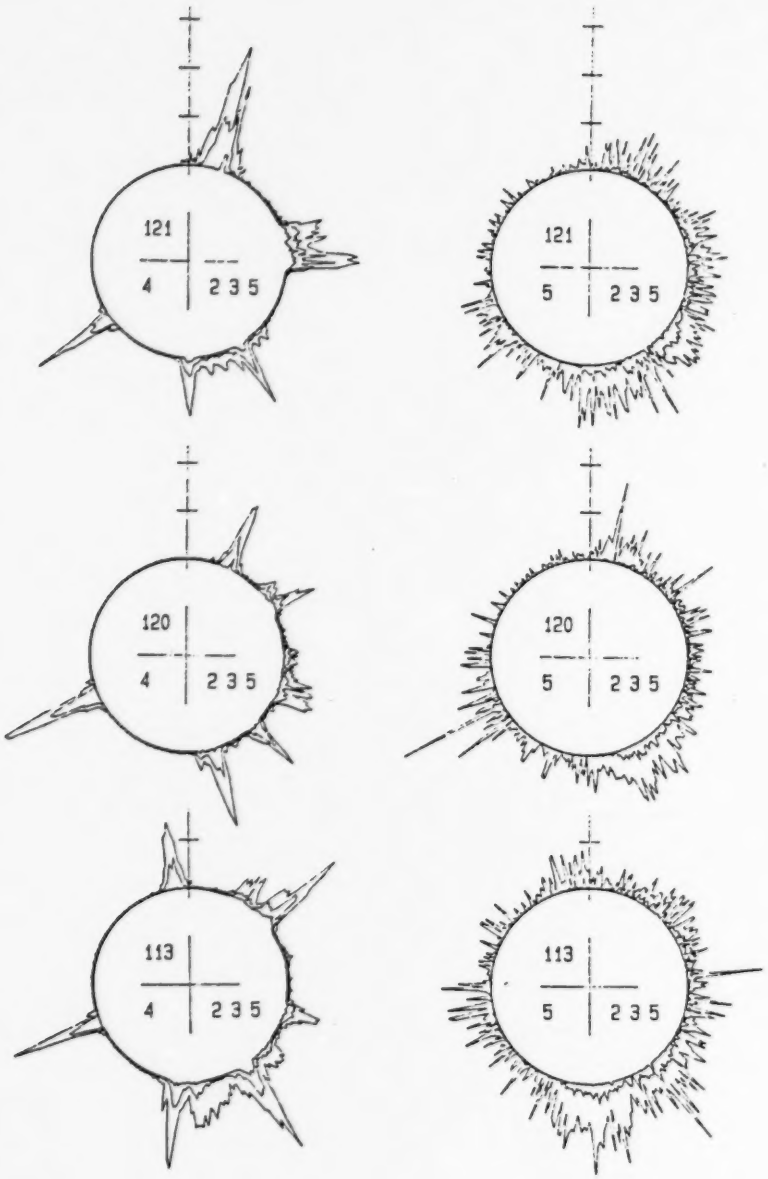

Figure 9. Modeled (left) and measured (right) "pollution zinnias" for sites 121, 120, and 113 (the western part of the grid).

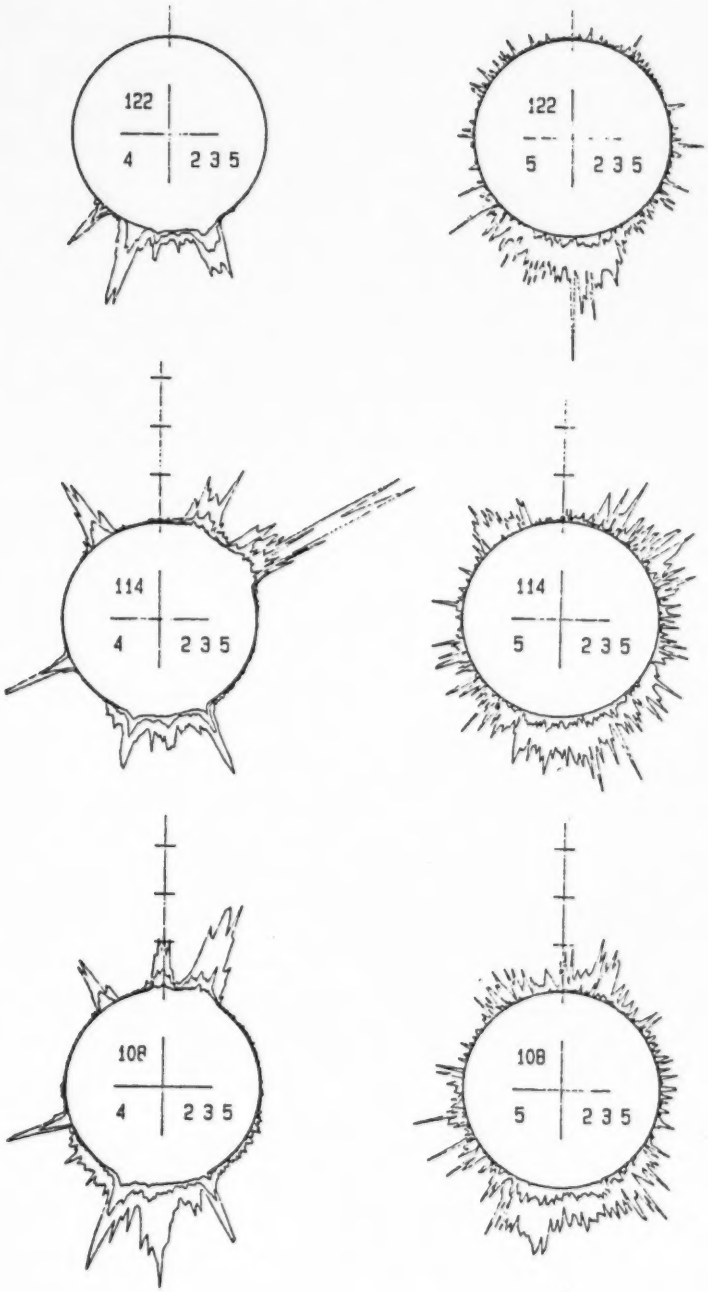

Figure 10. Modeled (left) and measured (right) "pollution zinnias" for sites 122, 114, 108 (the north-central part of the grid).